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By

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BLADES OF THE INITIAL STAGE

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FORMATION OF THE FLOW PATH OF A TURBINE BY UNDERCUTTING

BLADES OF THE INITIAL STAGE

A. M. Zavadovskiy, et. al.

The aerodynamic characteristics are given for a series of stages formed by undercutting the blades of the initial stage.

The work of the I. I. Polzunov Central Boiler and Turbine Institute [1] shows that at the present time it is advisable to form and calculate the flow paths of turbines by the method of "model stages".

This method specifies the formation of the flow path from the initial stage by undercutting the blades for the given operating conditions of a group of stages, and in certain cases, of the entire flow path of an individual turbine cylinder or of the turbine as a whole.

In order to be able to use the initial stage in the formation of the flow path, it is necessary that it have the following characteristics:

$$\eta_u^u = f\left(u/c_0'\right), \quad (1)$$

$$c_z/u = \varphi\left(u/c_0'\right), \quad (2)$$

$$y = c_z/c_0' = F\left(u/c_0'\right), \quad (2')$$

$$\varrho = f\left(D,\ u/c_0'\right), \quad (3)$$

$$\theta = F\left(S,\ \delta_p,\ u/c_0'\right), \quad (4)$$

$$\alpha_1,\ \beta_2,\ \alpha_2 = \varphi\left(D,\ t,\ u/c_0'\right), \qquad (5)$$

$$\left(u/c_0'\right)_{\text{opt.}} = f(\lambda), \qquad (6)$$

where η_u^u is the efficiency of the stage on the rim of the runner without using the output of the preceding stage;

u is the circumferential velocity for a mean diameter D_m;

c_0' is the velocity corresponding to the total drop to the stage;

c_z is the axial component of the velocity at the output of the stage;

ρ is the degree of reactivity;

θ is the use factor of the output velocity of the preceding stage;

α_1, β_2, α_2 are the angles of outflow from the channels of the flow path;

$$\lambda = D_m | l_r$$

where l_r is the height of the runner blade.

In addition, we need materials which would enable us to determine the change in the above-mentioned characteristics resulting from undercutting the blades and changing their widths.

The characteristics of the initial stage and the corrections to them can theoretically be obtained in two ways: a) by calculation and b) by testing the stage in rotation.

At the present time it is still impossible to obtain by the calculation method with acceptable accuracy for practical purposes the above-mentioned characteristics, and in particular the corrections to these characteristics related to undercutting the blades. At the present state of the investigations of the elements of the flow path such data can be obtained only by testing the initial stages in rotation. The calculation method at the present time can be used only during the designing of the initial stage. A stage thus designed requires, as a rule, adjustment during testing, in order to obtain aerodynamic and strength characteristics which qualitatively meet modern requirements.

At the present time our task is to create a series of initial stages which

would satisfy the requirements of steam- and gas-turbine construction.

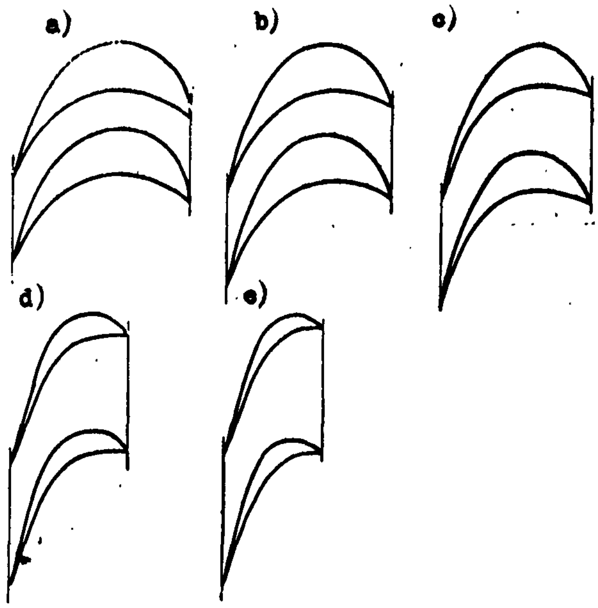


Fig. 1. Profiles of different cross sections of the runner blade and the channels formed by these profiles. Cross sections at the following distances from the root diameter:

a) 5.22 mm, b) 16.31 mm, c) D_m d) 49 mm, e) 60 mm.

The present article contains data concerning one of the initial stages developed at the Central Boiler and Turbine Institute, and it is shown that under certain conditions it is possible to considerably change the geometrical dimensions of the initial stages without any appreciable change in the efficiency, the flow characteristics, the reactivity, and other indices of the stage.

For stages with twisted blades the simplest case is to undercut the guide vanes of the initial stage on the side facing the turbine shaft and to undercut the runner blades from the top. From the point of view of the technology of manufacture of the blading such undercutting is very convenient and advantageous, since the blades are cut from the free end and the root does not shift relative to the root cross sections of the blades of the initial stage.

TABLE

Data on the Stages Studied at the Central Boiler and Turbine Institute

№ of stage	λ	Guiding apparatus								runner								
		D_m	l_g	b_g	B_g	z_g	t_g	$\bar{l}_g$	$\bar{t}_g$	D_m	l_r	b_r	B_r^*	z_r	t_r	δ_r	$\bar{l}_r$	$\bar{t}_r$
I	4,5	285,5	63,5	23,5	16	60	14,98	2,70	0,646	285,5	63,5	21,0	$\frac{10,0}{21,1}$	74	12,10	0.50 0,85 1,30	3,02	0,58
II	5,5	272	50	23,5	16	58	14,72	2,13	0,634	272	50	21,5	$\frac{13,2}{21,1}$	74	11,50	1,00 1,20 to 1,30 1,35 to 1,40	2,30	0,53
III	6,3	264	42	23,5	16	56	14,80	1,79	0,630	264	42	22,0	$\frac{15,0}{21,1}$	74	11,20	0,35 0,75	1,90	0,51
IV	7,4	257	35	23,5	16	54	14,96	1,49	0,640	257	35	23,0	$\frac{16,3}{21,1}$	74	10,90	0,30	1,60	0,46

* Numerators of fractions indicate width of blade at the top; denominators indicate width at root.

The initial stage has cylindrical guide vanes with a profile close to TH-2 TsKTI. The runner blades are twisted according to the law $c_u r^{\varphi^2 \cos^2 \alpha_1}$ = const. The initial profile of the runner blade (at the root) is similar to the root cross section of the first stage of the low-pressure section of the GT-12 LMZ.

Figure 1 shows the profiles of five cross sections along the height of the runner blade and the channels formed by these profiles. The lower pair of profiles refers to the cross section located at a distance of 5.22 mm from the base of the profile portion of the blades; the second pair refers to the cross section 16.31 mm from the base; the third pair of profiles is established for D_m; the fourth refers to the cross section 49.0 mm from the base of the blade, and the fifth pair refers to the cross section 3.5 mm from the peripheral portion of the blades.

The runner blades were undercut from the top during the tests. The number of these blades, as well as their angle of installation, remained the same in all the stages obtained after undercutting.

The guide vanes were undercut from their free ends. The number of them was varied in such a way that in the stages obtained after undercutting the pitch at the mean diameter was kept approximately constant. Detailed geometrical data concerning the stages studied are given in the Table. The design of the flow path of the initial stage is shown in Fig. 2.

The runner blades were unshrouded; the guide vanes were sealed at both ends into the turbine frame, so that there were no leaks between them and the rotor during the tests. This must be born in mind when using the test data given in this article.

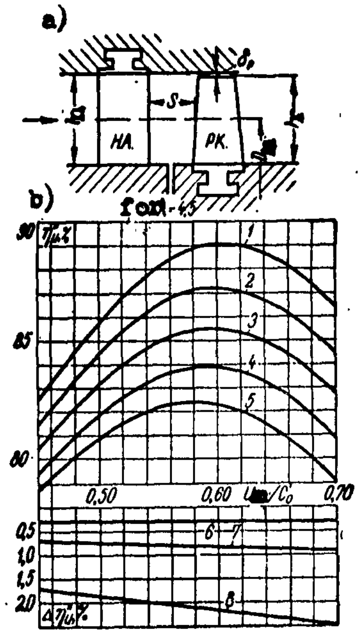
The angles of installation of the guide vanes γ_g were changed several times during the tests on each newly obtained stage. The limits of these angles were $38^\circ 30'$ and $46^\circ 30'$.

This led to a corresponding change in both the degree of reactivity and the streamline conditions of the runner blades with a resulting change in the efficiency.

Fig. 2. Design of the flow path (a) and efficiency on the rim η_u^* (b):

1) k = f/F = 0.005; 2) k = 0.010; 3) k = 0.015; 4) k = 0.020; 5) k = = 0.025; 6) $\lambda = D_m/l_r$ = 5.5; 7) λ = = 6.3; 8) λ = 7.4

Example: efficiency η_u^* when λ = 7.0, u/c_0' = 0.58 and k = 0.01, equals 87.1 - 1.7 = 85.4%.



In the basic tests the closed axial gap S amounted to 25 mm. In order to ascertain the effect of a change in the magnitude of this gap, certain tests were carried out at S = 10 to 40 mm.

The Re values (calculated from the chord of the blades) varied from $1.0 \cdot 10^5$ to $1.5 \cdot 10^5$.

The compressibility criteria reached M = 0.6.

The results of a study of the stages are shown in Figs. 2 to 8.

Figure 2 shows the values $\eta_u^u = f(u/c_0')$ at different values of the relative radial gaps obtained during testing of the initial stage with λ = 4.5.

As can be seen from the curves, the stage has very good efficiency indices. At gaps of 0.5 to 1.0%, the ones most often encountered in stages with long blades, the efficiency values on the rim of the runner without using the output velocity of the preceding stage at an optimum value of u/c_0' are equal to 0.87 to 0.89. This means that when used as an intermediate stage this stage will have an efficiency of 0.91 to 0.93 at the radial gaps usually encountered.

The uniform pressure fields at the output of the stage (Fig. 3) attest to the fact that the stage being investigated, even when playing the role of an intermediate

stage, will retain high efficiency values not only at the optimum value of u/c_0' but in the entire region of change in u/c_0' occurring in the tube installations.

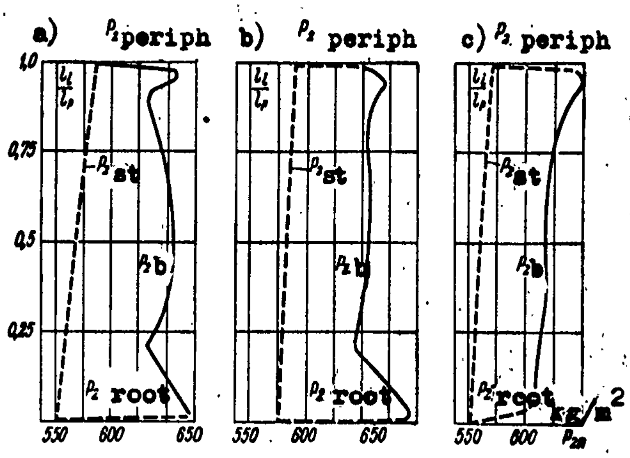


Fig. 3. The change in the total pressure (excess) behind the stage along the radius:
a) $u/c_0' = 0.475$; b) $u/c_0' = 0.575$
c) $u/c_0' = 0.650$.

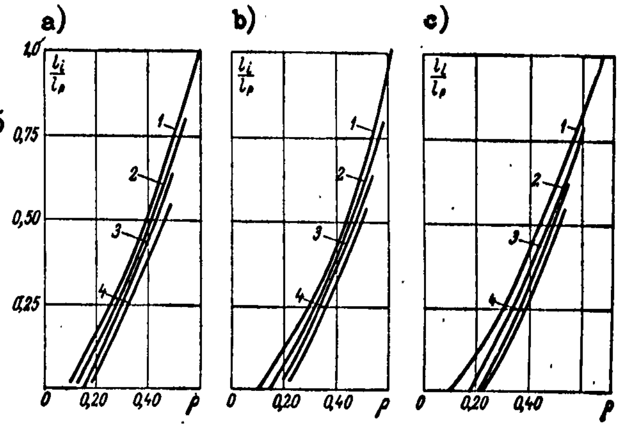


Fig. 4. The change along the radius of the degree of reaction in the stages:

a) when $u/c_0' = 0.475$ b) when $u/c_0' = 0.575$
c) when $u/c_0' = 0.650$

1) $\lambda = 4.5$; 2) $\lambda = 5.5$; 3) $\lambda = 6.3$;
4) $\lambda = 7.4$

The many data on the values of η_u^u obtained during the testing of the stages newly formed by undercutting blades with the same angle of installation of the guide vanes ($\gamma_g = 42^{\circ}30'$) showed that the values of η_u^u begin to decrease noticeably only when λ increases greatly. For example, when $u/c_0' = 0.6$, an increase in λ from 4.5 to 5.5 decreased η_u^u by 0.3%; an increase up to 6.3 decreased η_u^u by 0.8%. A noticeable decrease in η_u^u (by~2%) occurred only when the heights of the blades were decreased by 40% ($\lambda = 7.4$) by comparison with the initial stage ($\lambda = 4.5$). It should be noted that in this case the relative height of the blades $\bar{l}_r$ (see Table) decreased from 3.02 to 1.5.

The lower part of the graph in Fig. 2 gives the efficiency corrections which

take into account the change in λ as a result of undercutting with γ_g kept equal to $42^\circ30'$. In order to obtain the efficiency with undercutting taken into account, it is necessary in the case of the corresponding relative gap to determine the efficiency of the initial stage from the basic graph in Fig. 2 and from it subtract the $\Delta\eta_u^u$ for the corresponding λ. For a numerical example see Fig. 2.

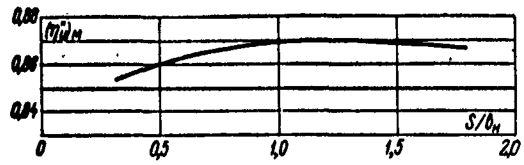
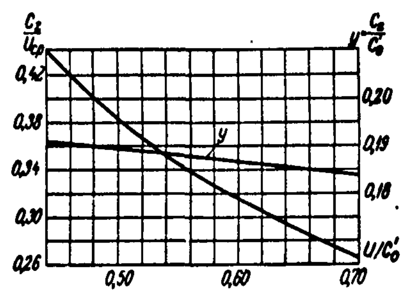


Fig. 5. The change in the efficiency of a stage as a function of the gap between the blade clusters.

Tests showed that when the blades are cut in one and the same cross sections the degree of reactivity increases. For example, in passing from $\lambda = 4.5$ to $\lambda = 6.3$ ρ increased from $\rho_p = 0.49$ to $\rho_p = 0.54$ on the periphery and from $\rho_r = 0.11$ to $\rho_r = 0.19$ at the root.

Consequently, leakages on the periphery and suction at the root are increased, and the streamlining of the runner blades deteriorates somewhat, thereby causing a decrease in efficiency.

Fig. 6. The change in the flow characteristics of the stage c_z/u and c_z/c_0' as a function of u/c_0' for the ratios $f/F_r = 0.005$ to 0.025.



An effective method making it possible to retain high efficiency during undercutting is to vary the angles of installation of the blades for the purpose of decreasing the degree of reactivity to optimum values. For example, when the angle of installation of the guide vanes γ_g was kept at $42^\circ30'$ and the blades were cut up to $\lambda = 6.3$, the efficiency decreased by $\Delta\eta_u^u = 0.8\%$. When the angle of installation of the guide vanes of the stage was changed to $\gamma_g = 40^\circ30'$, the decrease in efficiency by comparison with the initial stage amounted to only 0.3%. It is

interesting that the degree of reactivity decreased in this case: at the periphery ρ_p = 0.52 to 0.45, and at the root ρ_r = 0.20 to 0.12.

Figure 4 gives an idea of the degree of reactivity at different λ and u/c_0' and with an angle of installation $\gamma_g = 42^\circ 30'$.

Figure 5 shows the change in the maximum efficiency of the stage as a function of the closed axial gap. The shape of the curve corroborates the existing opinion concerning the determining role played in the given case by two basic factors: the effect of nonuniformity of the flow in front of the runner and friction losses on the annular surfaces.

Figure 6 shows the flow characteristics of the stages. The value of c_z/u was found to be practically the same in all stages under all regimes and for the entire zone of gaps being investigated. The same applies to the characteristic $y = c_z/c_0'$.

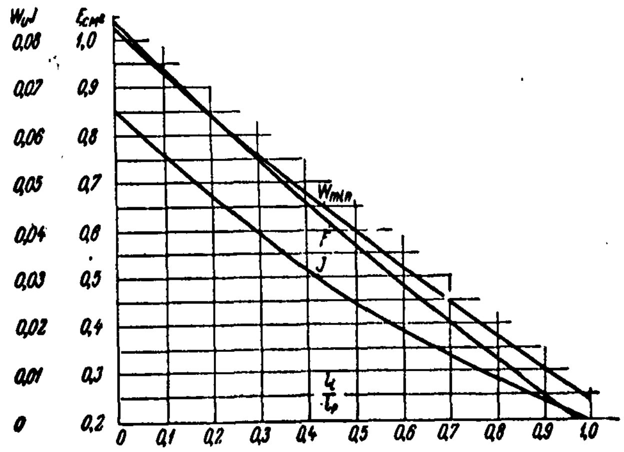


Fig. 7. Curves of distribution of areas and moments of resistance and inertia of the cross sections along the height of the blade.

From the initial stages it is necessary to present data characterizing the strength properties of the blades. In the case of the stage described in the present article these data are given in Fig. 7 in the form of curves of distribution of cross-sectional areas and of moments of resistance and inertia along the height of the blades.

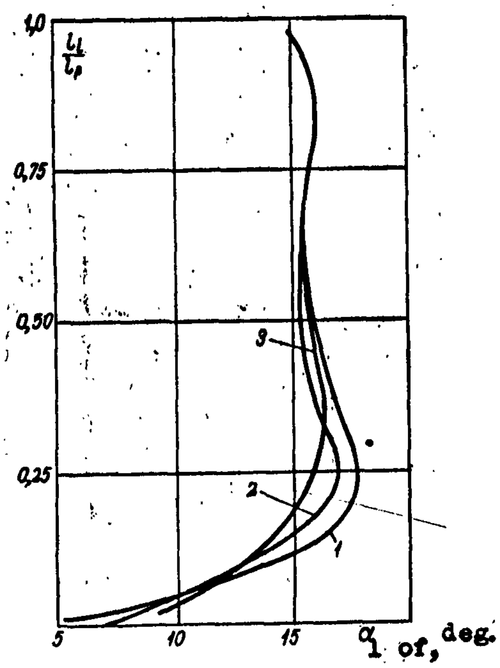


Fig. 8. The change along the radius of the angle α_1 in the initial stage for different regimes:

1) $u/c_0' = 0.475$; 2) $u/c_0' = 0.575$; 3) $u/c_0' = 0.650$

Figure 8 illustrates the direction of flow behind the guide vanes of the initial stage. The data are given for different regimes.

Conclusions

In order to form a blading apparatus satisfying modern technical and economic requirements, the method proposed in the present article can be used. It consists of the following:

A series of stages is formed from the initial stage by undercutting the runner blades from the periphery and the guide vanes from the side facing the shaft. In so doing the pitch of the guide vanes is kept constant at the mean diameter. In a large cutting of the blades a favorable value for the degree of reaction is achieved by varying the angle of installation of the guide vanes alone.

The recommended method of forming the flow path of turbines is simple and convenient from the point of view of the technology of manufacture and ensures the possibility of widely unifying turbine stages.

REFERENCES

1. A. M. Zavadovskiy and Kh. L. Babenko, Instructions for the Aerodynamic Calculation of the Flow Path of Stationary Gas Turbines, "Energomashinostroyeniye", No. 12, 1957.

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